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# ***Space Station Fluid Management Logistics***

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### Fluid Management Logistics Issues For Space Station Freedom Evolution

Recent changes in the configuration of the Space Station Freedom have resulted in increased logistics requirements. Selection of hydrazine for the propulsion and reboost system, and the changes to the Environmental Control and Life Support System have resulted in increased fluid resupply requirements. Coupled with this are future increases in fluid logistics requirements to support Station growth, and propellant storage and resupply requirements to allow Freedom to serve as a transportation node for future Lunar and Mars missions. These requirements will result in fluid resupply becoming an increasingly important part of Space Station Freedom operations. Development of automated fluid transfer operations and weight efficient fluid logistics carriers, designed to be compatible with several launch vehicles, will be required.

# **Fluid Management Logistics: Issues For Space Station Freedom Evolution**

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- Recent Design Changes Have Increased Fluid Logistics Requirements
  - Hydrazine Propulsion System Selection
  - Open-Loop Environmental Control/Life Support System
- Space Station Freedom Evolution Will Require Expanded Capability For Fluid Transport And Fluid Transfer Systems
  - Station Growth
  - Use As Lunar/Mars Transportation Node
- As Station Evolves, Fluid Resupply/Transfer Operations Will Take Larger Portion Of Crew Time And Launch Resources Requiring A System-Level Approach To Optimizing Fluid Logistics
  - Minimization Of Operations
  - Automated Fluid Transfer Operations
  - Weight Efficient Tankers

### Current Fluid Logistics Approach

The current logistics approach for resupplying fluids to the Space Station Freedom consists of an Unpressurized Logistics Carrier containing smaller subcarriers with the fluid tanks and hardware. The Unpressurized Logistics Carrier is designed for STS-launch compatibility only and for reusability. The Freedom propulsion and reboost system utilizes four propulsion modules with a capacity of 10000-12000 lbs of hydrazine each. These modules are self-contained with no capability for on-orbit fluid transfer. They are also designed for STS-launch only and are qualified for ~100 flights. All refurbishment/refueling takes place on the ground.

# **Current Fluid Logistics Approach**

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- Unpressurized Logistics Carrier Using Sub-Carriers For Fluid Resupply; Designed For Reusability (~100 Flights) And For STS Launch Only
- Hydrazine Propulsion/Reboost System
  - Resupply Via Changeout Of Modules
  - No Capability For Orbital Refueling; Modules Refueled/Refurbished On Ground
  - Designed For STS Launch Only (15 Ft Diameter)
  - Module Capacity 10000-12000 lbs

### Evolution Of Space Station Freedom Fluid Resupply

To satisfy the requirements for Space Station Freedom evolution, launch vehicles other than the STS must be employed. Launch vehicles that are being considered for use in future Freedom operations include Shuttle-C, Titan III and Titan IV, and the Advanced Launch System (ALS). The current STS-based Logistics elements will not be adequate to satisfy future fluid resupply requirements. More capacity will be required as well as the ability to transport large quantities of liquid hydrogen and liquid oxygen for Lunar/Mars mission support. In addition to increased fluid resupply requirements, fluid waste disposal requirements will likely increase as well. To meet these expanding requirements, fluid logistics elements of increased capacity and with launch compatibility with a variety of future Expendable Launch Vehicles will be required. In addition, totally expendable fluid resupply carriers can offer advantages, particularly in waste fluid disposal, that should be considered.

# **Evolution Of Space Station Freedom Fluid Resupply**

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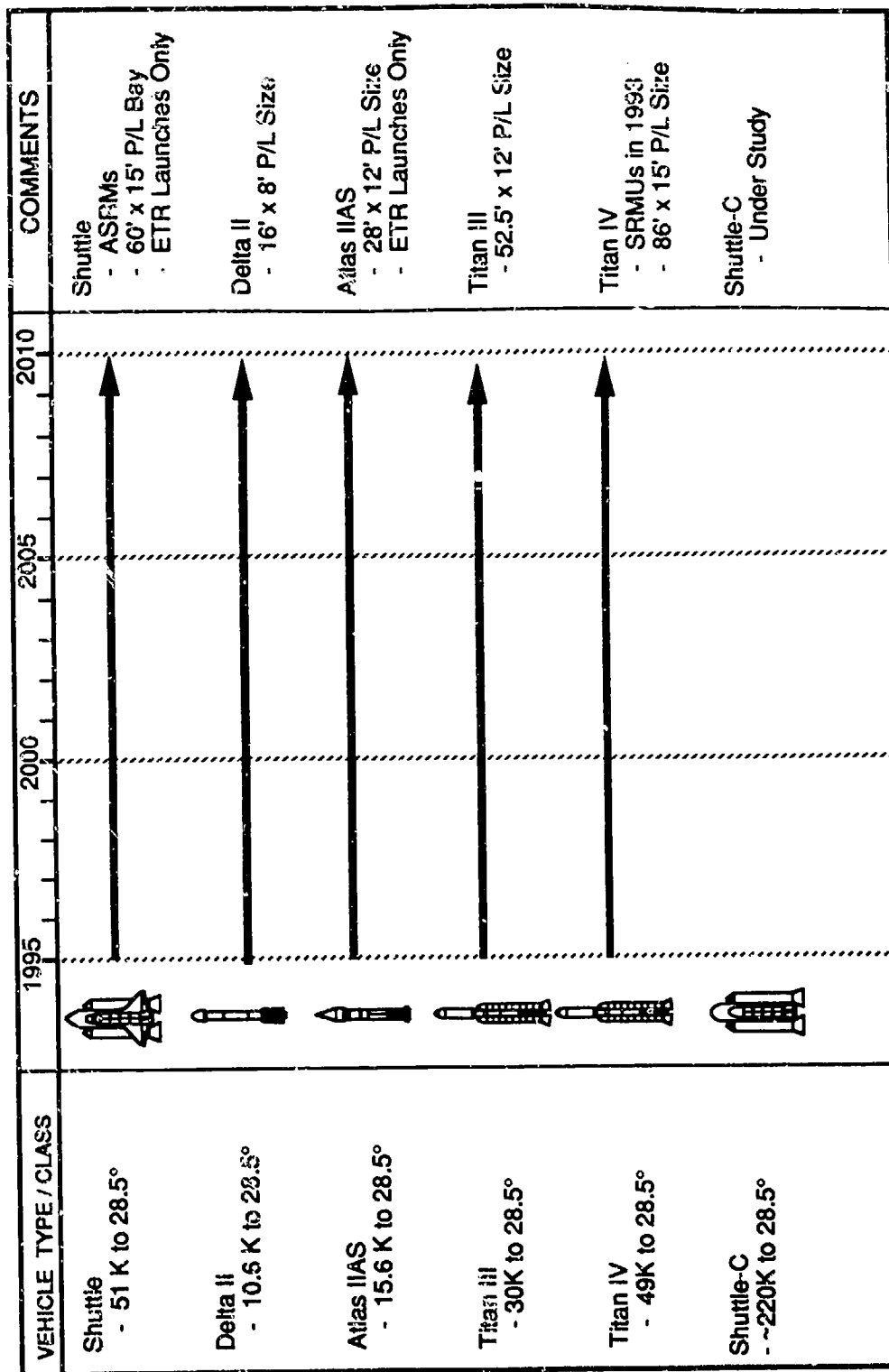
- Launch Vehicle Options Must Necessarily Expand Beyond STS To Satisfy Future Station Evolution (e.g. Shuttle-C, ALS, Titan Family)
- STS-Based Fluid Transportation/Resupply Systems Not Adequate For Station Evolution
  - More Capacity Required
  - Liquid Hydrogen/Liquid Oxygen Transportation For Lunar/Mars Support
- Waste Fluid Disposal May Become More Critical As Station Grows
- Fluid Transport And Resupply Systems Compatible With Multiple Expendable Launch Vehicles Desirable For Manifesting Flexibility
- Design Of Expendable Fluid Transport/Resupply Systems Offer Advantages In System Complexity And Operations That Should Be Considered

### Launch Vehicle Evolution

Current and planned launch vehicles that could support Space Station Freedom evolution are shown. The Advanced Launch Vehicle (ALS) is not shown due to uncertain development status. However, the Lunar/Mars mission scenarios must have a heavy lift vehicle such as ALS or Shuttle-C.



# Launch Vehicle Evolution



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### ELV Logistics System Approach

The approach to the use of an expendable ELV-based logistics carrier is summarized below. The ELV-based logistics carrier would be used in addition to the STS-based logistics carriers, thus providing an independent resupply capability resulting in additional payload capability to orbit and a reduction in STS manifesting. Also, the system, designed for the outset to be expendable, could be used as a waste disposal system with the capability to de-orbit more payload than it orbits (described later). The modular design of the carrier would allow resupply missions to be tailored according to specific needs.

# **ELV Logistics System Approach**

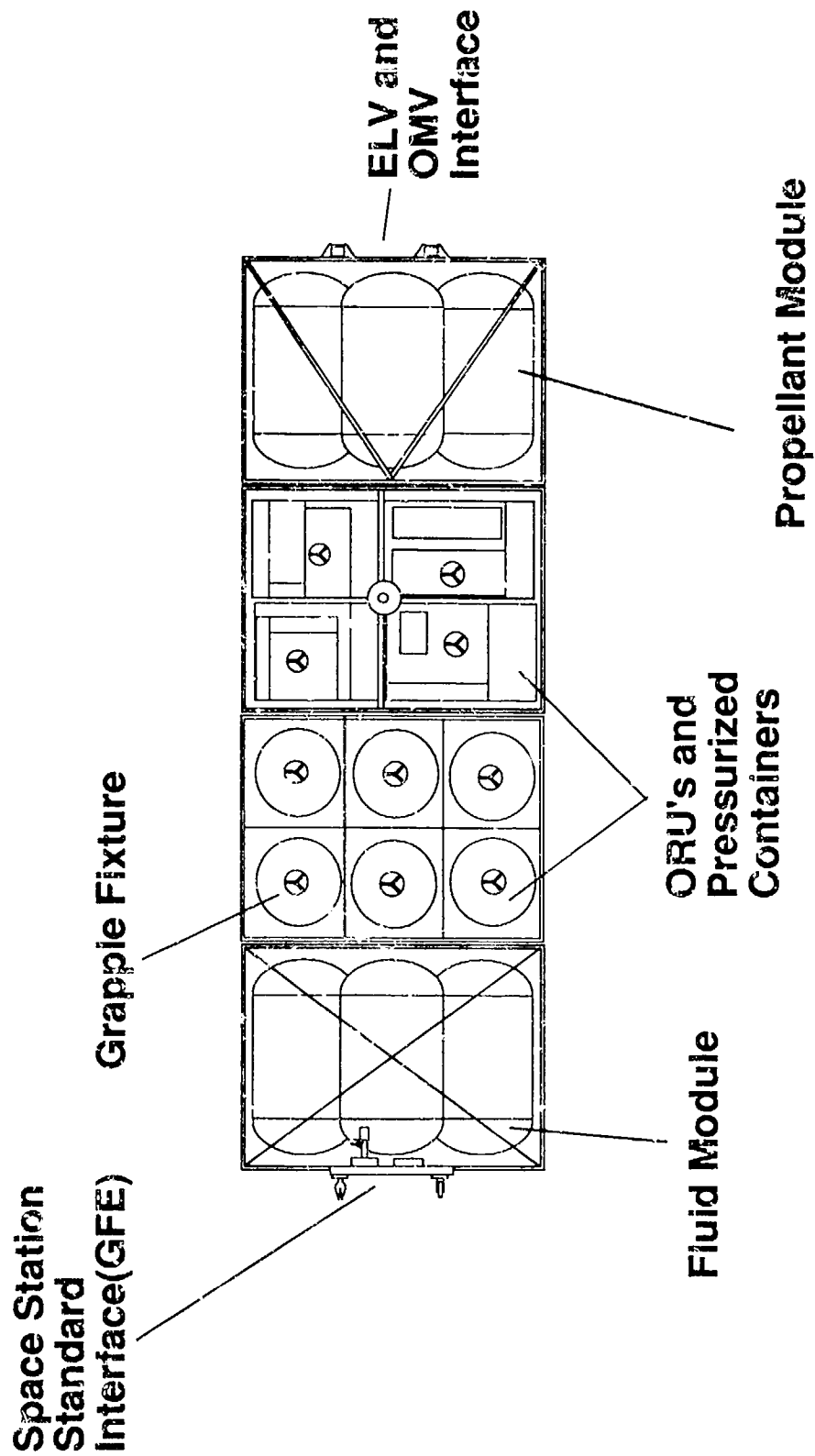
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- Utilizes ELV Instead Of A "Shuttle Only" Logistics System
- Provides An Independent Resupply Capability For Space Station And/Or Polar Orbit Systems
- Reduces Shuttle Manifest Crowding
- Provides Additional Capability To Resupply Fluids, ORU's, Dry Goods Containers And Enhances The Capability To Dispose Of Liquid And Solid Waste
- Increases System Flexibility For Resupply Of Fluids
- Reduces Space Station Mass Buildup Problem With The Capability To Deorbit More Weight (Waste/Trash) Than It Brings Up
- Modular Design Accommodates Special Logistics Mission Requirements
- Utilizes Low Cost "Throw Away" Logistics Carrier Approach - Trades Expendable Fluid Carrier Recurring Costs Versus Return/Refurbishment Costs Of Reusable Carrier

### Logistics Carrier Configuration

The overall configuration of the ELV-based expendable logistics carrier is shown below. The carrier consists of subelements for fluid/propellant resupply and dry goods resupply. The fluid module is used to resupply nitrogen, water, and high pressure gases. The propellant module contains hazardous propellants such as hydrazine for resupply of the Freedom propulsion system and the Orbital Maneuvering Vehicle (OMV). One end of the carrier contains a mounting interface with the ELV and OMV payload adapters and the opposite end a standard Space Station interface, containing all of the fluid and electrical umbilicals. The dry goods carrier can resupply both pressurized and unpressurized cargo. Pressurized cargo is accommodated in pressurized containers that are equipped with grapple fixtures to allow removal by the Space Station manipulator arm for transfer to the pressurized modules. The carrier can be flown in varying configurations such as all fluids/propellants or all dry goods or both.

# Logistics Carrier Configuration



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Expendable Fluid/Propellant Carrier Description

The key design features of the fluid/propellant carrier are summarized below.

## **Expendable Fluid/Propellant Carrier Description**

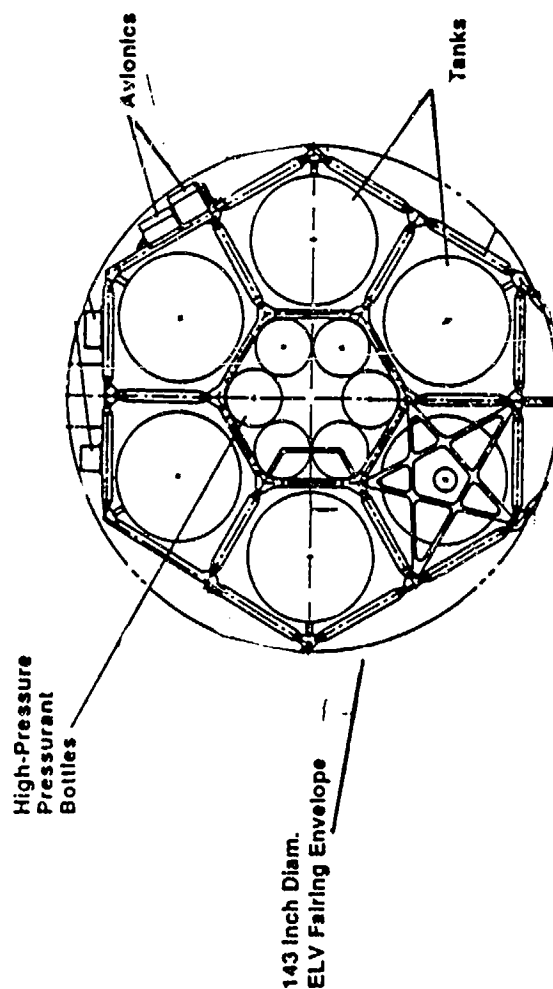
- Modular Design To Accommodate High Pressure Gas And Liquid Tanks
- Qualified For One Flight
- Utilizes Existing Tanks
- Welded Aluminum Truss Structure With Ample Design Margins
- Minimum Avionics And Power Subsystems - Uses Freedom-Provided Resources
- Passive Thermal Control (Blankets And Coatings)
- Space Station Freedom Avionics Controls All Orbital Fluid Transfer Operations
- Equipped With Common Interface Hardware (Umbilicals, Mechanisms, etc.)
- Interface Provided To Accept Waste Fluids From Stations Subsystems
- Man-Rating Achieved By Combination Of On-Board And Station-Based Components

### Fluid Carrier Design Concept

The configuration of the fluid/propellant carrier is shown below. The accompanying table summarizes the total carrier weight. The fluid/propellant carrier is designed to fit within a typical ELV payload fairing ( $\geq 12$  ft. diameter). Up to six tanks carried with a total capacity of 6000 lbs of hydrazine or water, resulting in a mass fraction of 0.77. Space is provided for high pressure gas bottles although these would not be required if Space Station-supplied nitrogen is available or if Station-based pumps are used to transfer the fluids. A minimum of electronics is carried to interface with the Station avionics system which would monitor and control the carrier.



# Fluid Carrier Design Concept



Subsystem	Weight, lbs
Fluids Carrier	
• Thermal	81
• Truss Structure	350
• Mechanisms	70
• Avionics	25
• Tanks	500
• Fluid Components	50
Propellant Capacity	6000
Total Wet Weight	7766
Mass Fraction	0.77
Dry Goods Carrier	
• Structure	350
• Mechanisms	20
• Thermal Control	50
Mass Fraction	Depends On Cargo Density

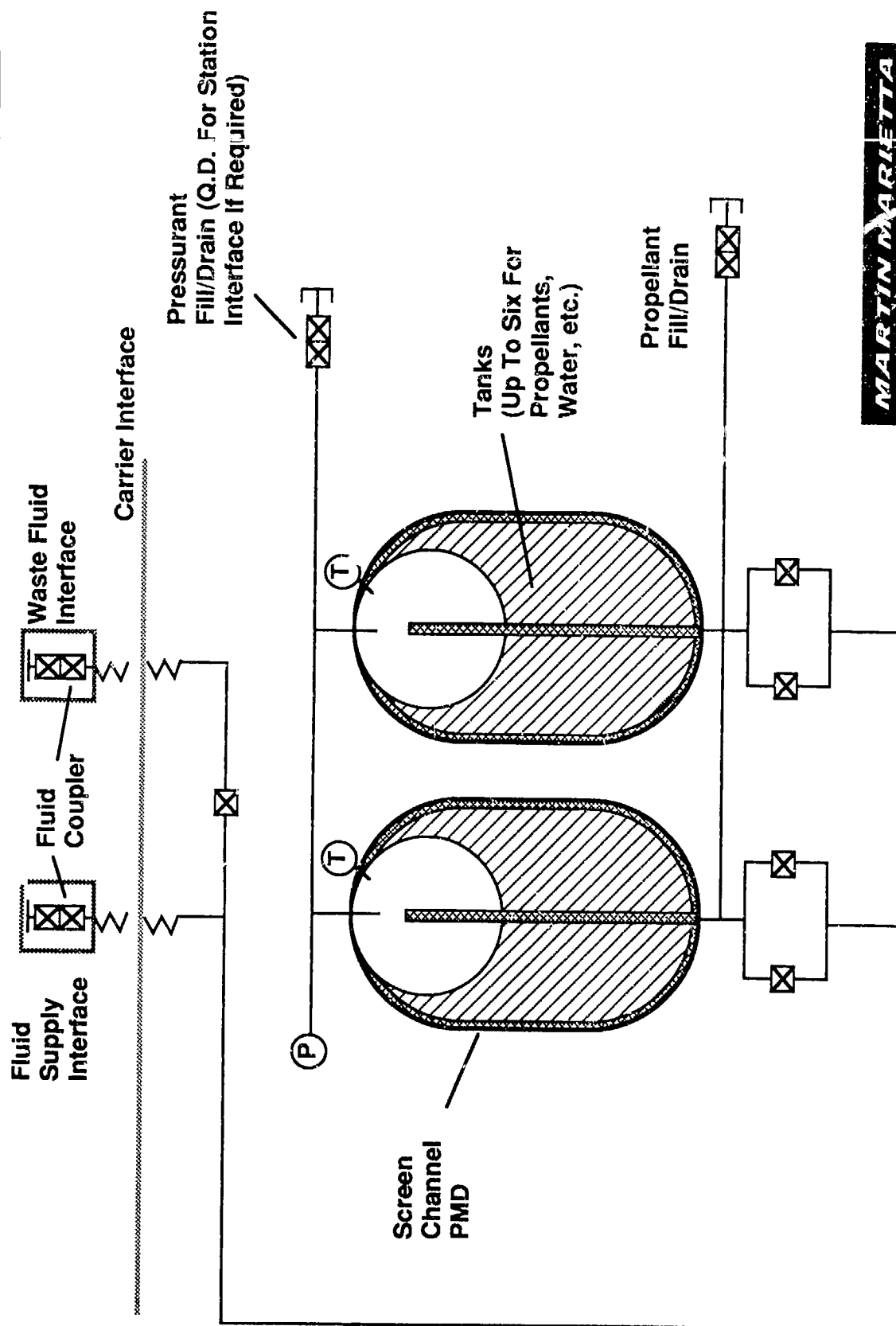
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### Expandable Fluid Carrier Schematic

The schematic of the fluid/propellant carrier is shown on the facing page. For clarity, only two of the six tanks are shown. Since the carrier is launched on an EI V, the STS requirement of two failure tolerance to leakage in the payload bay is not required. However, once the carrier is attached to the Space Station, full man-rating will be required. This redundancy is achieved by considering that the carrier is part of an overall fluid storage and transfer system. Man rating is obtained by the use of on-board components and Station-based components.

Two fluid interfaces are provided, one for fluid transfer to the Space Station Freedom, and one for transfer to the carrier of waste fluids. The waste fluid interface would be kept dry by valving on the Station side of the interface until the carrier is empty to avoid contamination of the supply fluid. Once done, the waste fluid is transferred into the carrier until full.

# Expendable Fluid Carrier Schematic

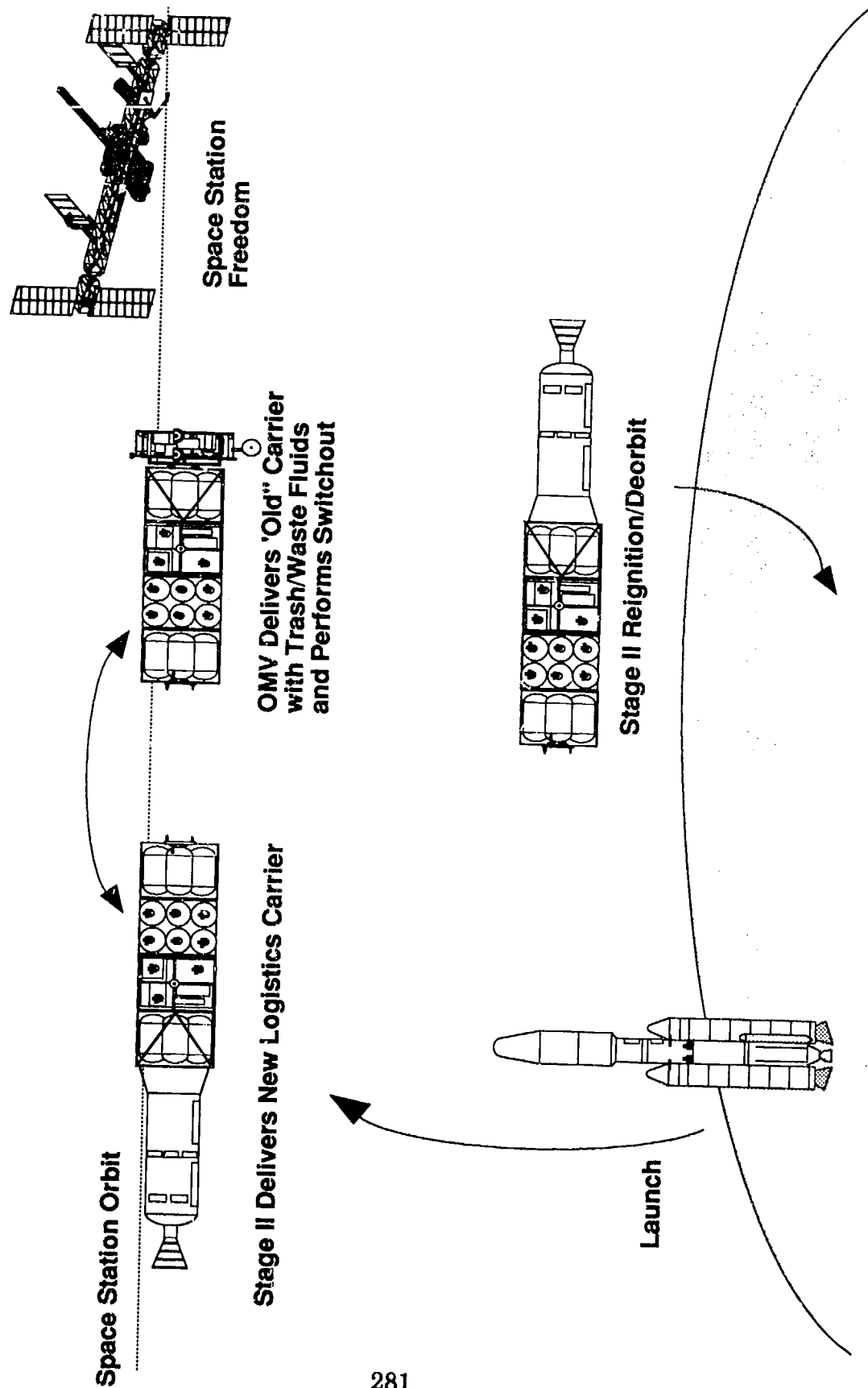


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### Logistics Carrier Orbital Operations

The orbital operations for the expendable logistics carrier begin by launch directly into the Space Station orbit by the ELV second stage or upper stage. The OMV, carrying a used carrier filled with waste fluids and trash would rendezvous and trade carriers with the ELV stage. The would be accomplished by deployment of the carrier from the ELV via a spring-type release mechanism and attachment of the old carrier to the ELV by the OMV. The OMV would then dock to the new carrier and transport it to the Space Station. The ELV second stage would then reignite, deorbiting itself and the old carrier for disposal in the ocean. Considering the Titan III as the launch vehicle, a carrier weighing 24000 lbs could be launched to the Station and an old carrier weighing 30000 lbs could be deorbited. Therefore, use of the expendable logistics carrier allows both consumables and waste fluids/trash to be handled on a single ELV launch.

# Logistics Carrier Orbital Operations



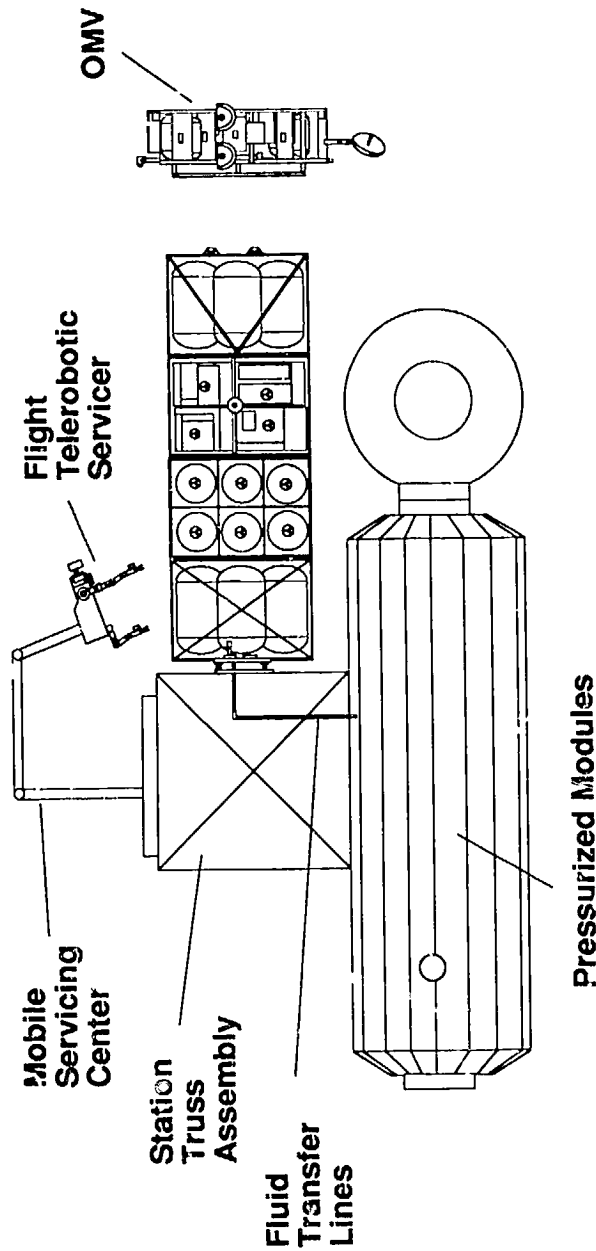
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### Carrier Operations At Space Station

Operations of the expendable logistics carrier begin with attachment of the carrier to the Station truss assembly by the Station Manipulator Arm or by directly by the OMV. After mating of the fluid and electrical couplings, the fluid transfer operations would occur as required using Station avionics for control and monitoring. Simultaneously, dry goods would be transferred as required into the pressurized modules or to the truss structure either by the manipulator arm or by the Flight Telerobotic Servicer. Transfer of appropriate waste fluids into the fluids/propellant carrier would be performed as required. The carrier would remain attached until the next logistics carrier is launched.

## Carrier Operations At Space Station

- Carrier Docked To Station Truss Via Station Manipulator Arm
- Fluid/Electrical Umbilical Mating
- Fluid Transfer Operations As Required
- Dry Goods Transfer To Pressurized Modules Via FTS Or Manipulator Arm
- Waste Fluid Transfer Into Empty Carrier Tanks
- Transport To ELV For Disposal By OMV



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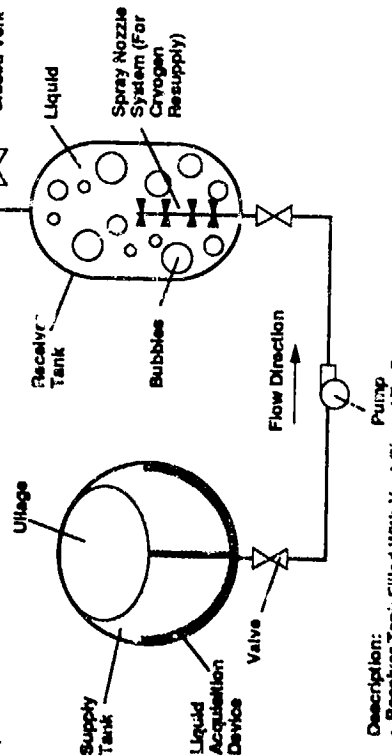
### Summary/Status Of Orbital Fluid Transfer Techniques

As stated in an introductory chart, simple techniques for the transfer of fluids on-orbit must be developed that will lend themselves to automatic control due to the probability of limited crew time. The fluid transfer technique is a key driver in the configuration of the fluid resupply system, including the logistics carrier. The facing page summarizes the state-of-the-art in fluid transfer techniques, including the processes involved and the status concerning testing, analysis, etc. The three categories shown, "no-vent" fill, ullage transfer, and vented fill, are broad categories only. Specific fluid resupply systems have been proposed that use variations of these techniques, but generally they fall into one of these three categories. Of the three, only the "no-vent" fill technique has been demonstrated on-orbit (hydrazine via the NASA JSC Orbital Resupply System (ORS) flight demonstration and water via the Martin Marietta Storable Fluid Management Demonstration (SFMD) orbital experiment). More orbital testing of these techniques via a system-level demonstration is required to support fluid logistics evolution. Also, development of software to automatically control and monitor the fluid transfer process (particularly for large systems) will be required. Simplification of the fluid transfer process will be desirable to simplify the software.



# Summary/Status Of Orbital Fluid Transfer Techniques

## "No-Vent" Fill Technique



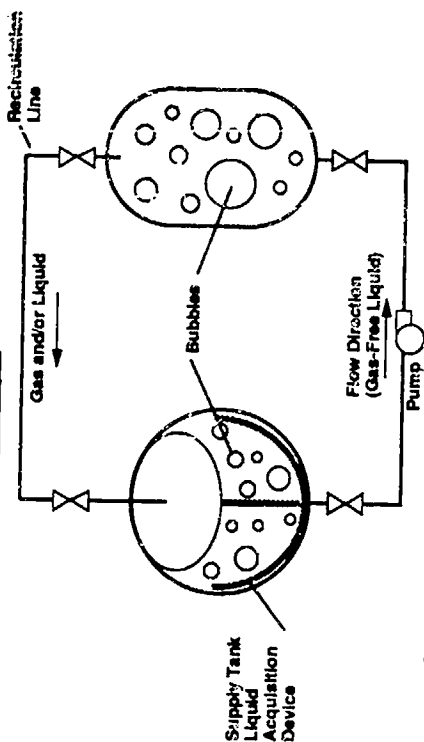
**Description:**

- Receiver Tank Filled With Vent Closed To Prevent Loss Of Incoming Liquid
- Fill Process Compresses Ullage In Receiver Tank
- Filling Through Spray Nozzle System Proposed For Cryogen Resupply To Promote Vapor Condensation For Tank Pressure Control

### Status:

- Demonstrated On-Orbit For Water And Hydrazine
- Limited On-Orbit Testing For Cryogenics

## Ullage Transfer Technique



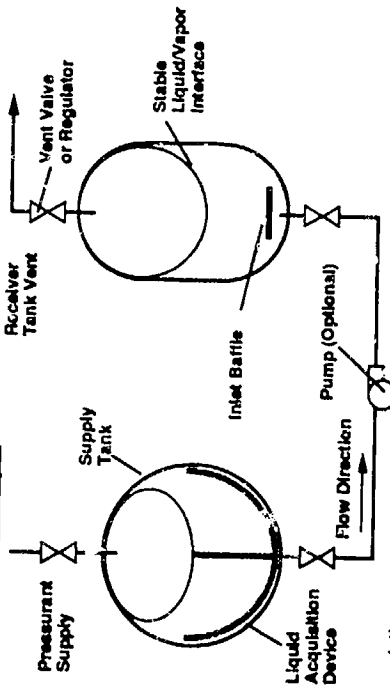
### Description:

- Supply Tank And Receiver Tank Vent Lines Interconnected
- Supply Tank Liquid Acquisition Device Used To Filter Any Gas That Escapes Through Receiver Tank Vent Line

### Status:

- Proposed For Both Storable (OSCP's Program) And Cryogenic Resupply
- No Orbital Testing To Date

## Vented-Fill Technique



### Description:

- Receiver Tank Filled With Vent Open As In One Gravity
- Surface Tension Force Of Liquid Utilized To Form Stable Interface So That Only Vapor Is Vented From Tank

### Status:

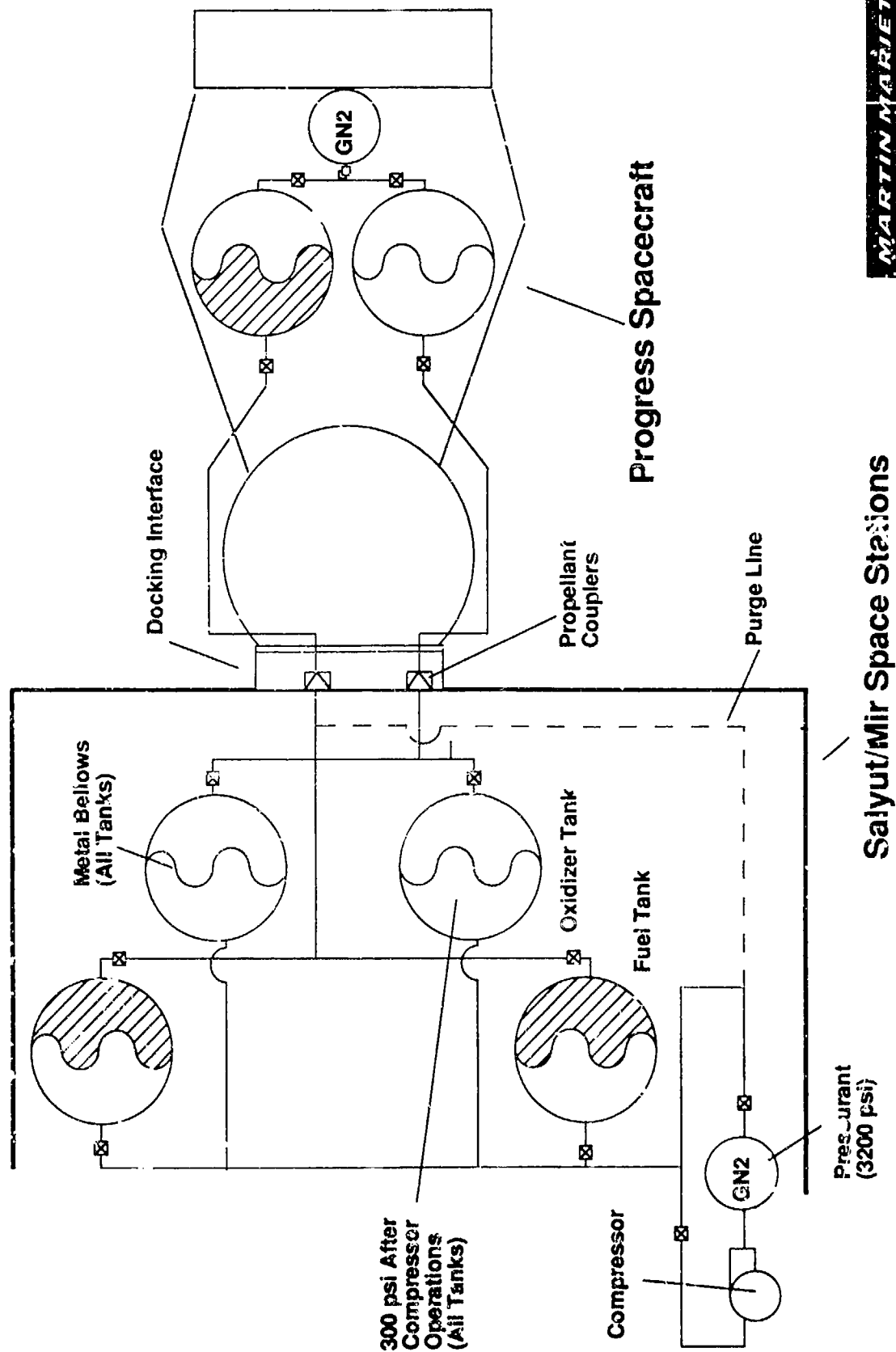
- Drop Tower Testing And Limited Analysis With CFD Codes
- No Orbital Testing

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### Soviet Progress Tanker System: Schematic

The role of an expendable fluid/propellant carrier and operational techniques for fluid transfer can be seen in examination of the Soviet Progress tanker system. The Progress tanker system has been successfully operating for over ten years performing propellant resupply operations in a semi-automatic mode. The unmanned Progress tanker is used to resupply the earlier Soviet Salyut and the current Mir space station's regulated bipropellant propulsion systems as well as resupplying dry goods. The fluid transfer system is shown on the facing page. The Progress/Station fluid interfaces are mated upon docking and are then leak checked via high pressure gas. The fuel and oxidizer couplers are located on opposite sides of the docking ring to maximize physical separation in case of leaks. Both coupler halves are dry during the docking operation. Once the leak check has been completed, a 1 Kw compressor on the Mir is used to reduce the pressure in the station propellant tanks to about 300 psi to allow propellant to be pressure transferred from the Progress tanks. The compressor, with a 10:1 compression ratio, discharges into the station pressurant storage tanks, thereby reusing the pressurant gas. All tanks on the station side and the Progress side utilize a metal bellows (or similar device) propellant management device which prevents contamination of the nitrogen pressurant gas by the propellant, thereby making it safe to recompress. After the pressure reduction has been completed (a process that took several shifts on the Salyut space stations due to power limitations), propellant is then transferred from the Progress tanker; fuel and oxidizer being performed separately for safety. Once propellant transfer operations are complete, the fuel and oxidizer lines are purged using gaseous nitrogen by dumping a small amount of raw propellant overboard. This is done to ensure that, upon Progress undocking, the coupler halves are dry, eliminating concerns over a stuck-open disconnect.

# Soviet Progress Tanker System Schematic



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### Soviet Propellant Resupply System Observations

Examination of the Soviet Progress tanker system results in several observations as to their philosophy in designing and operating an expendable fluid resupply system. First, the fluid transfer operations are performed without crew involvement unless a contingency occurs. Fluid transfer is performed automatically with the ground controllers monitoring the operations. The Soviets accept a small quantity of vented propellants to prevent mating a wet fluid coupler. This probably results in relatively simple coupler since two-fault tolerance to leaks via three seals is not required. Finally, resupply of pressurant gas has been eliminated by use of the metal bellows propellant management device and the on-board compressor, saving resupply system launch weight at the expense of extra power usage on-orbit.

# **Soviet Propellant Resupply System Observations**

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- Soviet Progress Tanker System Operational For >12 Years
- Propellant Transfer Performed Without Crew Involvement Unless Contingency Occurs
- Transfer Of Fuel And Oxidizer Done Separately ; Quick Disconnects Located On Opposite Sides Of Docking Ring For Maximum Physical Separation
- Metal Bellows Device Plus The Compressor Prevents Pressurant Contamination And Allows Reuse Eliminating Need For Pressurant Gas Resupply; Benefits Of A Regulated Propulsion System Are Retained
- Soviets Accept Small Quantity Of Raw Propellant Vented Overboard To Eliminate The Need To Demate A Wet Quick Disconnect; Possibly Results In Simpler Connector (No Triple Redundant Seals)
- Power Consumption Of Compressor (1 Kw) Deemed Preferable To Additional Weight For Pressurant Resupply

### Fluid Logistics Evolution - Conclusions

The conclusions reached in this evaluation of Space Station Freedom fluid logistics evolution are summarized below. First, development of fluid logistics carriers that are both expendable and capable of launch on ELV's would provide a needed increase in capacity as well as providing a fluid/trash disposal system. This will be of increasing importance as Station evolution forces an increase in fluid resupply requirements. Launching large quantities of hazardous propellants, particularly cryogenics, on an unmanned vehicle will simply operations and safety concerns. On-orbit fluid resupply techniques and software to automatically transfer fluids are required. An increase in fluid launch capacity may simplify fluid transfer operations by allowing simpler methods to be used. Development and system-level demonstrations of fluid transfer systems including transfer techniques and automated software are needed. Finally, simplification of the fluid logistics elements can be achieved by consideration of man-rating on a system level basis, helping to avoid the need for single components to be two-fault tolerant.

# **Fluid Logistics Evolution - Conclusions**

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- Development Of Fluid Logistics Elements With ELV Launch Compatibility
- Expendable Fluid Resupply Systems Provide Attractive Mission Operations Advantages (e.g. Waste Disposal, Less Complexity)
- Use Of ELV's For Evolutionary Fluid Resupply Will Relieve STS Manifesting Concerns; Permits Large Quantities Of Hazardous Propellants To Be Launched On Unmanned Vehicle
- Operational Simplicity May Be Driver For Fluid Transfer Operations Not Minimization Of Fluid Losses During Process
- Fluid Transfer Procedures/Systems Adaptable To Automated Operations (With Manual Override) Need Development And Demonstration
- Fluid Resupply Redundancy/Reliability Should Be Worked At System Level; Avoids Placing Two-Fault Tolerance On Single Components (e.g. Couplers)